Efficiency of rotary nickel–titanium K3 instruments compared with stainless steel hand K-Flexofile. Part 1. Shaping ability in simulated curved canals

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Abstract

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Aim To compare the shaping ability of K3 rotary nickel–titanium instruments with stainless steel K-Flexofiles manipulated by hand. Part 1 of this two-part report describes the efficiency of these two instruments in simulated curved root canals.

Methodology Simulated canals with $28°$ and $35°$ curves in resin blocks were prepared by K3 instruments with a rotational speed of 250 r.p.m. using a crown-down preparation technique, or by K-Flexofiles using a reaming motion ($n = 24$ canals in each case). All canals were prepared up to size 35 at the end-point of preparation. Pre- and postinstrumentation images were recorded, and assessment of canal shape was completed with a computer image analysis program. Material removal was measured at 20 measuring points, beginning 1 mm from the apex. Incidence of canal aberrations, preparation time, changes of working length and instrument failures were also recorded.

Results In comparison with stainless steel K-Flexofiles, rotary K3 instruments achieved better canal geometry and showed significantly less canal transportation ($P < 0.05$). Eleven K3 instruments and none of the K-Flexofiles fractured during preparation ($P < 0.05$). Between both the canal types, K3 was significantly faster ($P < 0.001$) than K-Flexofiles. Both instruments maintained a good working distance.

Conclusions K3 instruments prepared curved canals rapidly and with minimal transportation towards the outer aspect of the curve. Fractures occurred significantly more often with K3.

Keywords: canal transportation, curved root canals, nickel–titanium, resin blocks, root canal preparation, rotary instruments.

Introduction

Several nickel–titanium instruments have been developed recently for use in a rotary technique. All of the new systems incorporate instruments with a taper greater than the ISO standard 0.02 design; indeed, rotary nickel–titanium instruments are available with tapers ranging from 0.04 to 0.12 (Thompson & Dummer 1997a, Bergmans *et al.* 2001). These greater taper instruments have been introduced to improve the cutting efficiency of nickel–titanium instruments, to reduce the incidence of instrument failures and to enhance canal shape in order to allow more apical placement of the irrigant and to facilitate root canal filling, especially when using thermoplastic obturation techniques (Bergmans *et al.* 2001).

Besides variation in taper, nickel–titanium rotary instruments are characterized by different cross-sections and designs of blades (Bergmans *et al.* 2001). In general, rotary files having a positive rake angle differ from those possessing U-shaped blades with radial land areas (Bergmans *et al.* 2001). Due to these flat areas, the rake angle of these files is neutral or slightly negative; thus, canal enlargement is thought to occur through planing

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of dentine rather than a cutting action and chip dislodgement (Bergmans *et al.* 2001). It is well known that the cutting efficiency of a file depends upon the rake angle of its cutting blades (Wildey *et al.* 1992). Since dentine is a dense and resilient material, instruments having a negative rake angle are less efficient and require more energy to cut dentine than files with a positive rake angle (Wildey *et al.* 1992).

With regard to the cutting efficiency of rotary root canal instruments, a positive rake angle would tend to result in efficient chip dislodgement (Wildey *et al.* 1992, Bergmans *et al.* 2001). So, other rotary instruments, such as Hero 642 (Micro Méga, Besançon, France) or Quantec files (Tycom, Irvine, CA, USA) have a helical cross-section resulting in a slightly positive rake angle (Bergmans *et al.* 2001). These instruments have no radial lands (Bergmans *et al.* 2001).

The K3 instrument (SybronEndo, West Collins, CA, USA) is reported to have a slightly positive rake angle in combination with so-called radial land relief and asymmetrical cross-sectional design (Bergmans *et al.* 2001) (Fig. 1). The peripheral blade relief areas (Fig. 1) are alleged to have two functions: (i) to increase the peripheral mass in order to increase the instruments' resistance to fracture and (ii) to reduce the amount of area of the radial lands that comes in contact with the canal wall in order to reduce frictional resistance.

To date, little information on the mechanical properties and shaping ability of nickel–titanium K3 instruments is available. The K3 instruments are made of 55-nitinol (Florek 2003), and have flattened noncutting tips and a rounded transitional angle (Fig. 2). Twenty K3 instruments are available: sizes 15–60 have two different tapers (0.04 and 0.06). The manufacturer recommends that root canals be enlarged with these instruments using the crown-down technique (Stock 2001).

The purpose of this study was to compare automated K3 rotary nickel–titanium instruments with stainless steel hand K-Flexofiles (Dentsply Maillefer, Ballaigues, Switzerland), used in a reaming motion during the shaping of simulated curved root canals in resin blocks.

Materials and methods

Simulated canals

Simulated canals made of clear polyester resin (Viapal uP 004/64, Vianova Resins, Hamburg, Germany) with coloured canal walls were used to assess instrumentation. The degree of curvature was either 28° or 35°. The diameter and the taper of all simulated canals were equivalent to an ISO standard size 15 root canal instrument. The 28° canals were 13 mm long, the straight part being 5.5 mm and the curved part 7.5 mm. The curvature was defined mathematically with a radius of 7.5 mm resulting in an angle of 28°, according to the Schneider method (Schneider 1971). The 35° canals were 13 mm long, the straight part being 5 mm and the curved part 8 mm. The radius of curvature was 6.5 mm.

Preparation of simulated canals

The simulated canals were prepared with either K3 rotary nickel–titanium instruments or with stainless
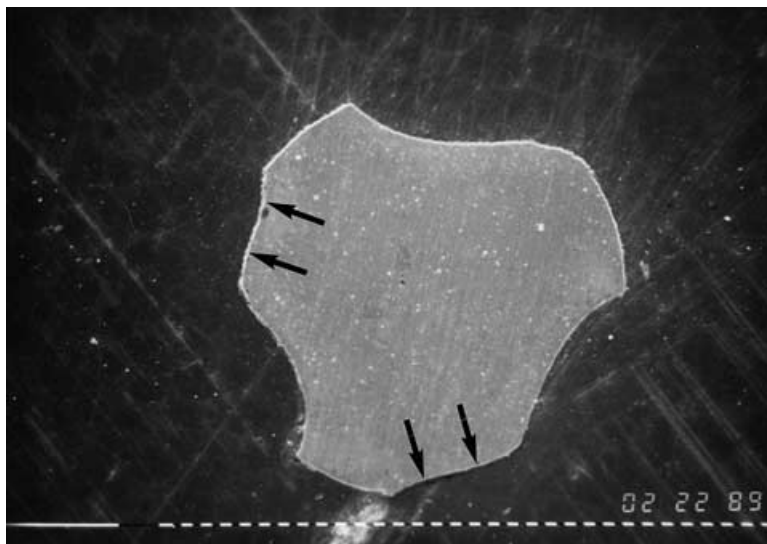

Figure 1 Scanning electron microscope image of the cross-section of a K3 instrument (0.06 taper size 30; original magnification 160×) showing radial land relief areas (indicated by arrows). The cross-section of the K3 file is asymmetrical.
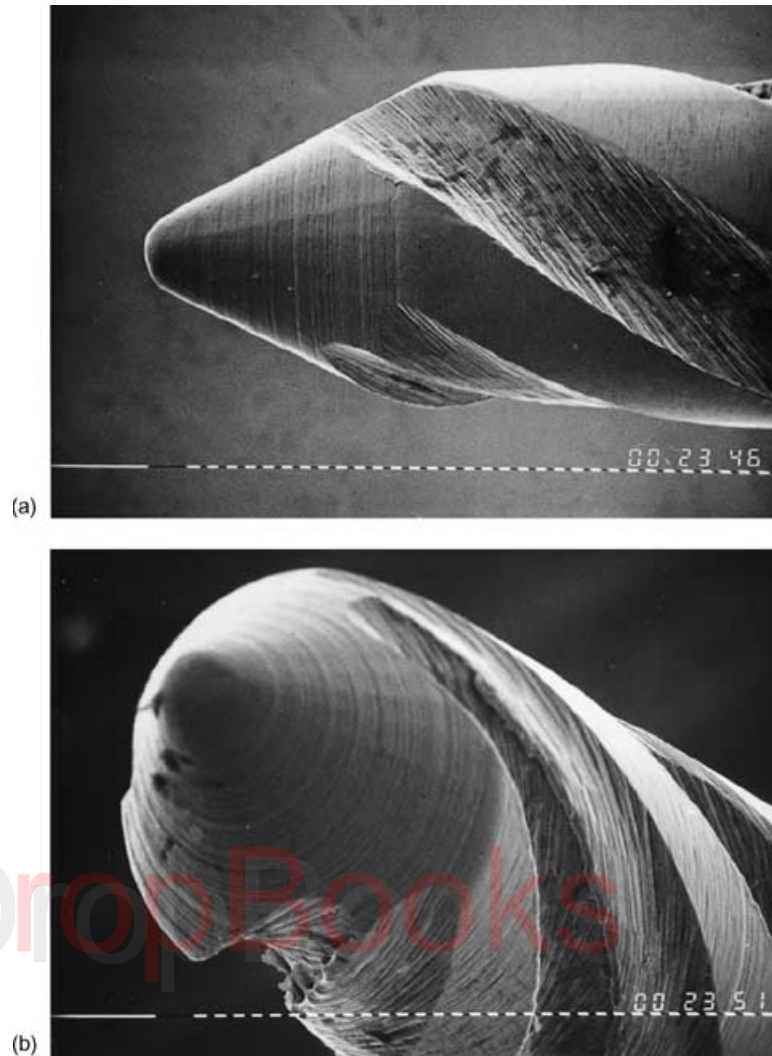
Figure 2 Scanning electron microscope images of the tip region of K3 instruments showing a noncutting, flattened tip with rounded transitional angles.(a) 0.06 taper size 30; original magnification 160×.
(b) 0.06 taper size 30; original magnification 160×.

steel hand K-Flexofiles. The transparent blocks were covered with adhesive tape during the preparation phase. All instruments were used to enlarge one canal only. Prior to use, each instrument was coated with glycerine to act as a lubricant, and copious irrigation with water was performed repeatedly after the use of each instrument. All canals were enlarged by an operator experienced in both manual instrumentation with stainless steel K-Flexofiles and automated preparation with K3 files. Measurement of the canals were carried out by a second examiner who was unaware of the experimental groups. A randomly laid down sequence was used to avoid bias towards one of the two instrumentation techniques. Only six resin blocks (three with 28° curves and three with 35° curves) were instrumented at a time to minimize operator fatigue and familiarity. These six

resin blocks were defined as a set. The order of use of the two instrument types within a set was rotated. All canals were enlarged to an apical size 35. The following instrumentation sequences were used with the different instruments:

Group A: K3 instruments were set into permanent rotation (250 r.p.m.) with a 18 : 1 reduction handpiece (K3 handpiece, W & H, Buermoos, Austria), powered by a torque-limited electric motor (K3etcm, Kerr, Karlsruhe, Germany) using torque setting 3, which is as stated by the manufacturer to be equivalent to a torque limitation of 1.2 N cm. Instrumentation was completed in a crown-down manner according to the manufacturer's instructions using a gentle in-and-out motion. Instruments were withdrawn when resistance was felt and changed for the next instrument. In a pilot study the

following instrumentation sequence allowed preparation of the different canals without difficulties:

1 A 0.06 taper size 20 instrument was used to 7 mm.

2 A 0.04 taper size 30 instrument was used to 9 mm.

3 A 0.06 taper size 25 instrument was used to 9 mm.

4 A 0.04 taper size 25 instrument was used to 11 mm.

5 A 0.04 taper size 20 instrument was used to 13 mm, the full length of the canal.

6 A 0.04 taper size 25 instrument was used to 13 mm, the full length of the canal.

7 A 0.04 taper size 30 instrument was used to 13 mm, the full length of the canal.

8 A 0.04 taper size 35 instrument was used to 13 mm, the full length of the canal.

Once the instrument had negotiated to the end of the canal and had rotated freely, it was removed.

Group B: Hand instrumentation with the K-Flexofile stainless steel instruments with noncutting tips was performed using a reaming motion. Thus, the instruments were manipulated in a clockwise rotation of about 90–120° until it reached the full working distance. A step-back method of instrument manipulation was not used. All canals were sequentially prepared from size 15 up to 35 without prebending the instruments, which were used to 13 mm, the full length of the canal.

In each of these two test groups, 24 canals with 28° and 24 canals with 35° curves were enlarged. Thus, a total of 96 canals were prepared.

Assessment of canal preparation and analysis of data

The time for canal preparation was recorded, and the total active instrumentation, instrument changes within the described instrumentation sequence and irrigation was included. Changes of working length were determined by subtracting the final length (measured to the nearest 0.5 mm) of each canal after preparation from the original length (13 mm). The preparation time and the loss of working length were statistically analysed using the Mann–Whitney *U*-test at a significance level of $P < 0.05$. The number of fractured and permanently deformed instruments during enlargement was also recorded. A chi-square test was used to determine whether there were significant differences between the two instruments concerning instrument failure and deformation of instruments.

The assessment of preparation shape was carried out with the computer program Image 1.41 (National Institutes of Health public domain program). Therefore, pre- and postinstrumentation canal shapes were taken in a standardized manner and magnified 40 times by means of a charged coupled device (CCD) camera (SSC-M370CE, Sony Corporation, Tokyo, Japan) and stored in the computer (Macintosh Quadra 660 AV, Apple Computer, Ismaning, Germany). Thereafter, a composite image was produced of the pre- and postinstrumentation images and superimposed. The amount of resin removed, e.g. the difference between the canal configuration before and after instrumentation, was determined both for the inner and the outer side of the curvature in 1-mm steps using the Image 1.41 program. The amount of resin substance removed in all canals was measured one-dimensionally with a precision of ±0.01 mm. The first measuring point was 1 mm away from the apical ending of the canal, the last measuring point was 10 mm from the apical end, resulting in 10 measuring points at the outer and 10 points at the inner side of the canal, and thus, in a total of 20 measuring points (Schäfer *et al.* 1995, Tepel 1997), all measurements were made at right angles to the surface of the canal. The data were analysed by the Mann–Whitney *U*-test, because for some measuring points the data was not distributed normally according to the Kolmogorov–Smirnov test.

Furthermore, based on the superimposition of pre- and postoperative images, assessments were made according to the presence of different types of canal aberrations, such as apical zip associated with elbow, ledge and perforation. These different types of canal aberrations were defined according to the detailed descriptions published recently (Thompson & Dummer 2000b).

Results

During preparation of the 96 canals, a total of 11 instruments were separated. Therefore, the following results are based on the remaining 85 canals. Five canals with 28° and six canals with 35° curves were excluded.

Instrument failure

Table 1 details the number of deformations and fractures of instruments that occurred during the study. All failures occurred at the tip region of the instruments. Independent of the curvature of the canals, none of the

Table 1 Number of fractured and permanently deformed instruments

Instrument	28°-curved canals		35°-curved canals	
	Fractured	Deformed	Fractured	Deformed
K3	5	8	6	9
K-Flexofile	0	5	0	6

Table 2 Number of separated K3 files with respect to size and taper

Taper and size	28°-curved canals	35°-curved canals
0.04 size 20	2	0
0.04 size 25	1	0
0.04 size 30	2	6

Table 5 Incidence of canal aberrations by instrument types

Aberration type	28°-curved canals		35°-curved canals	
	K3	K-Flexofile	K3	K-Flexofile
Zip/elbow	2	5	2	6
Ledge	2	5	4	6
Perforation	0	0	0	0

χ^2 test, no significant differences ($P > 0.05$).

stainless steel K-Flexofiles separated. In the 28°-curved canals, five K3 instruments separated, and in the 35°-curved canals six nickel–titanium instruments separated (Table 2). The number of separated instruments ($\chi^2 = 5.442$; $P < 0.05$) was significantly higher for the K3 files whilst the number of permanently deformed instruments ($\chi^2 = 0.011$; $P = 0.918$) was not significantly different between the instrument types.

Preparation time

The mean time taken to prepare the canals with the different instruments is shown in Table 3. Independent of the curvature of the canals, the shortest mean preparation time was recorded when K3 instruments were used. Both in 28°- and 35°-curved canals, K3 was significantly faster than K-Flexofiles ($P < 0.001$).

Change of working length

All canals remained patent following instrumentation; thus, none of the canals became blocked with resin shavings. None of the canals showed overextension of preparation, whereas a loss of working distance was found in several canals.

The mean loss of working length that occurred with the different instruments is listed in Table 4. The

Table 3 Mean preparation time (min) and SD with the two different instruments

Instrument	28°-curved canals		35°-curved canals	
	Mean	SD	Mean	SD
K3	6.92	0.51	6.49	0.81
K-Flexofile	13.34	1.24	13.43	1.09

Table 4 Mean loss of working length (mm) and SD with the two different instruments

Instrument	28°-curved canals		35°-curved canals	
	Mean	SD	Mean	SD
K3	0.28	0.18	0.35	0.24
K-Flexofile	0.41	0.21	0.49	0.28

differences between the two instrument types were not statistically significant, in either the 28°- ($P = 0.074$) or 35°-curved canals ($P = 0.096$).

Canal shapes

The results concerning the assessment of canal aberrations are summarized in Table 5. With respect to the different types of aberrations evaluated, both in canals with 28° and with 35° curves, there were no significant differences between the two instrument types (χ^2-test; $P > 0.05$), but more zips and more ledges were created with K-Flexofiles.

On average, in the canals with 28° curves, K3 instruments removed material more evenly on the outer as well as on the inner side of curvature (Fig. 3a). With the exception of two measuring points, significant differences ($P < 0.05$) occurred between resin removal achieved with the two different instruments (Table 6). The canals prepared with K3 instruments remained better centred compared with those enlarged with K-Flexofiles (Fig. 3).

In the canals with 35° curves, K3 instruments removed more material on the outer side of the curvature (Fig. 4a). In average, only limited material removal occurred in the inner side of the curvature in the apical part of the canals (Table 7). Canals shaped with K-Flexofiles had material removed mainly in the last 1–5 mm along the outer side of the curvature, resulting in severe outer widening of the canal (Fig. 4b). This effect was significantly different compared with the material removal achieved with K3 files at these five measuring points ($P < 0.001$). In general, the K3 instruments showed a more centred enlargement compared with the K-Flexofiles (Fig. 4).

Discussion

The purpose of this study was to compare the relative efficiency and shaping ability of rotary K3 nickel–titanium instruments with stainless steel hand K-Flexofiles. K-Flexofiles were chosen as controls since it is well known
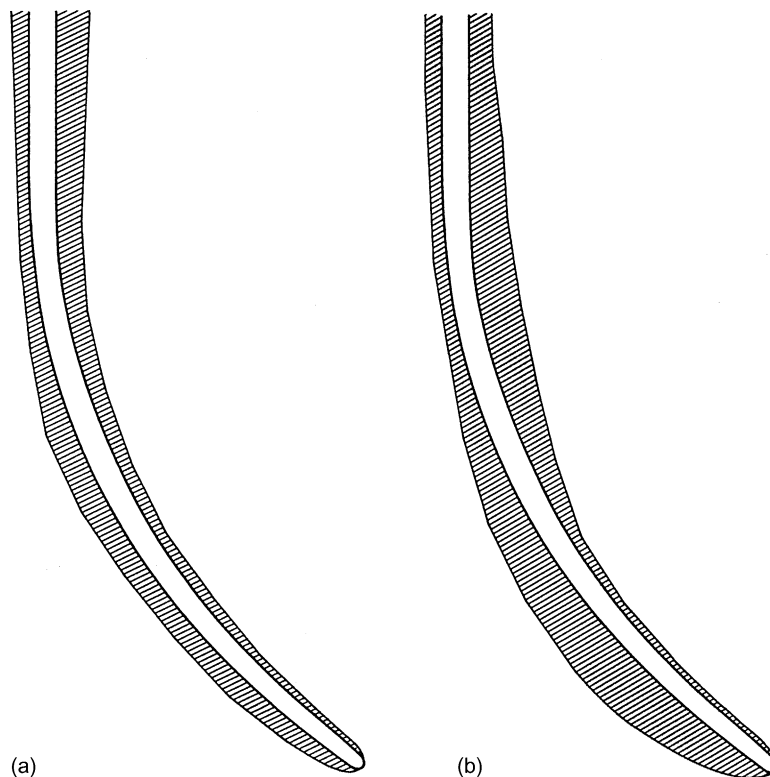
(a)

(b)

Figure 3 Mean changes in the canal shape of 28°-curved canals as the result of instrumentation with (a) rotary nickel–titanium K3 instruments and (b) stainless steel hand K-Flexofiles ($n = 24$ canals in each case).

that out of all hand instruments used in a rotary motion, these instruments displayed the greatest cutting efficiency (Tepel *et al.* 1995) and most ideal shape (Al-Omari *et al.* 1992, Schäfer *et al.* 1995). Moreover, the shaping ability of some rotary nickel–titanium instruments has already been compared with that of the K-Flexofiles (Kum *et al.* 2000, Bertrand *et al.* 2001, Park 2001, Schäfer 2001, Schäfer & Lohmann 2002a,b). Because there is no evidence in the literature that K-Flexofiles are better used in a linear or rotational working motion (Bishop &

Dummer 1997), these instruments were used in a reaming motion as the present K-file has a triangular cross-section. The K-Flexofiles were not used in a crown-down or balanced-force manner since a pilot study showed that these techniques did not result in better instrumentation results compared with the sequence used in the present study.

This study described the shaping abilities of the instruments under strictly controlled laboratory conditions, using clear resin blocks. Use of simulated canals in resin

Table 6 Mean material removed (mm) and SD at the different measuring points after instrumentation of simulated 28°-curved canals

	Inner canal wall (mm from the apex)										Outer canal wall (mm from the apex)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
K3																				
Mean	0.07	0.07	0.07	0.08	0.10	0.14	0.23	0.28	0.32	0.23	0.17	0.19	0.19	0.22	0.26	0.23	0.16	0.11	0.09	0.12
SD	0.04	0.04	0.05	0.05	0.07	0.08	0.09	0.10	0.09	0.11	0.05	0.06	0.05	0.06	0.07	0.08	0.07	0.07	0.07	0.08
K-Flexofile																				
Mean	0.01	0.02	0.02	0.11	0.27	0.38	0.48	0.39	0.36	0.23	0.42	0.54	0.58	0.48	0.37	0.24	0.11	0.06	0.05	0.10
SD	0.01	0.01	0.02	0.05	0.07	0.07	0.07	0.10	0.09	0.08	0.07	0.04	0.07	0.09	0.13	0.12	0.10	0.07	0.06	0.07
P-value	***	***	***	0.072	***	***	***	***	***	**	***	***	***	***	***	0.455	*	**	**	**

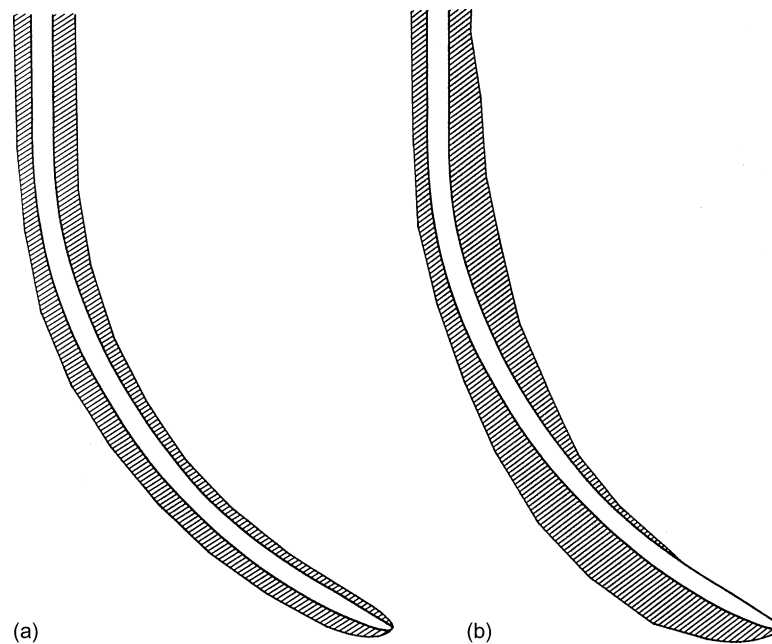$^* = P < 0.05$; $^{**} = P < 0.01$; $^{***} = P < 0.001$.

Figure 4 Mean changes in the canal shape of 35°-curved canals as the result of instrumentation with (a) rotary nickel–titanium K3 instruments and (b) stainless steel hand K-Flexofiles (*n* = 24 canals in each case).

(a)   (b)

blocks does not reflect the action of the instruments in root canals of real teeth. However, resin blocks allow a direct comparison of the shaping ability of different instruments (Schäfer *et al.* 1995). A major drawback of using rotary instruments in resin blocks is the heat generated, which may soften the resin material (Kum *et al.* 2000), and lead to binding of cutting blades and separation of the instrument (Thompson & Dummer 1997c, Baumann & Roth 1999). Thus, owing to the nature of the resin, care should be exercised in the extrapolation of the present results on failure of the K3 instruments to the use of these instruments in real root canals, where dentine is involved (Thompson & Dummer 1997c).

In comparison with the stainless steel K-Flexofiles, rotary K3 instruments achieved better canal geometry,

showed less canal transportation and straightening (Figs 3 and 4) and created fewer canal aberrations (Table 5), both in canals with 28° and 35° curves. The ability of rotary nickel–titanium instruments to maintain the original shape of curved canals has been confirmed by several studies (Thompson & Dummer 1997a,b,c,d, Baumann & Roth 1999, Kum *et al.* 2000, Park 2001, Schäfer 2001, Schäfer & Lohmann 2002a). However, similar to other rotary nickel–titanium instruments, the K3 files created a slight canal transportation toward the outer aspect of the curvature in the apical region of the canals, especially in those having 35° curves (Thompson & Dummer 1997d, 1998, 2000b, Baumann & Roth 1999, Park 2001, Schäfer & Lohmann 2002a). The canal transportation may be due to the root

Table 7 Mean material removed (mm) and SD at the different measuring points after instrumentation of simulated 35°-curved canals

	Inner canal wall (mm from the apex)										Outer canal wall (mm from the apex)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
K3																				
Mean	0.08	0.08	0.09	0.09	0.11	0.13	0.20	0.29	0.30	0.24	0.15	0.18	0.19	0.20	0.24	0.25	0.19	0.14	0.13	0.16
SD	0.05	0.06	0.06	0.06	0.08	0.07	0.09	0.09	0.09	0.07	0.05	0.05	0.06	0.05	0.05	0.07	0.07	0.06	0.07	0.08
K-Flexofile																				
Mean	0	0.02	0.02	0.10	0.25	0.36	0.44	0.46	0.38	0.26	0.46	0.60	0.69	0.58	0.38	0.24	0.17	0.15	0.14	0.16
SD	0.01	0.01	0.03	0.07	0.08	0.11	0.11	0.12	0.13	0.13	0.13	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.11
P-value	***	***	***	0.573	***	***	***	***	0.070	0.714	***	***	***	***	***	0.098	0.668	0.231	0.245	0.651

* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

canal preparation with instruments of greater taper, since these are stiff as compared with those of ISO taper (Kum *et al.* 2000, Thompson & Dummer 2000b). In contrast, canals enlarged manually with K-Flexofiles showed a more marked transportation toward the outer aspect of the curves and, although not statistically significant (Table 4), had a higher incidence of canal aberrations (Al-Omari *et al.* 1992, Bishop & Dummer 1997, Kum *et al.* 2000, Park 2001, Schäfer 2001, Schäfer & Lohmann 2002a).

In several studies, the shaping ability of different rotary nickel–titanium instruments and flexible stainless steel hand K-files have been compared. These studies corroborate the findings of the present investigation in that in severely curved simulated canals the use of different rotary nickel–titanium instruments such as ProFiles (Kum *et al.* 2000, Park 2001), GT files (Park 2001), Hero 642 files (Schäfer 2001) and FlexMaster (Schäfer & Lohmann 2002a) resulted in less canal transportation, fewer canal aberrations and less instrumentation time compared with stainless steel K-Flexofiles.

In the present study, none of the canals became blocked with resin shavings, and none of the canals showed overextension of preparation. Thus, the only changes of working length was a loss of working distance. In general, it was possible with both types of instruments to control the working distance well (Table 4). This finding is in agreement with several observations of other studies in that only small mean changes in working distance occurred with rotary nickel–titanium instruments (Kum *et al.* 2000, Thompson & Dummer 2000a, Schäfer & Lohmann 2002a). On the whole, it is questionable whether the small changes of working length observed in the present study may have any clinical significance. These changes may be due to minor canal straightening during canal enlargement or lack of length control by the operator (Thompson & Dummer 2000a).

The mean time for canal preparation was recorded, and included instrument changes within the described instrumentation sequences. Both, in the 28°- and 35°-curved canals, the K3 instruments were significantly faster than hand preparation with K-Flexofiles (Table 3). This is in agreement with the findings of several authors that instrumentation times with rotary nickel–titanium instruments are substantially faster than with stainless steel hand instruments (Thompson & Dummer 1997a,b,c, Kum *et al.* 2000, Thompson & Dummer 2000a, Schäfer 2001, Schäfer & Lohmann 2002a).

During the present study, no fractures occurred with K-Flexofiles, whereas 11 K3 instruments separated. It is worth emphasizing that these all were 0.04 taper instruments (Table 2). To date, no data is available on the torsional properties of the K3 instruments, therefore no explanation can be given why these particular instruments were susceptible to separation. Related to the total number of K3 instruments used, a fracture rate of approximately 3% (11 out of 373 K3 files used when all instruments were used to enlarge one canal only) resulted. However, related to the total number of 48 simulated canals enlarged with these instruments, a separation rate of approximately 23% occurred. In comparison with previously published studies conducted under the same experimental conditions as used in the present investigation, the separation rate of K3 files was considerably higher compared to the fracture frequency of Hero 642 and FlexMaster instruments (Schäfer 2001; Schäfer & Lohmann 2002a). Thus, when using K3 files, according to the instrumentation sequence described in the present study, the separation rate of K3 instruments was higher than previously reported fracture rates of newer rotary nickel–titanium instruments (Thompson & Dummer 1997a, Baumann & Roth 1999, Kum *et al.* 2000, Thompson & Dummer 2000a). Since up to now, the manufacturer has not recommended a particular preparation sequence for severely curved canals, further research is necessary to investigate the influence of different instrumentation sequences on the separation rate of K3 instruments.

Conclusions

In conclusion, within the limitations of this study, K3 instruments prepared curved canals rapidly, with few canal aberrations and minimal transportation towards the outer aspect of the curve, but with an increased risk of instrument separation. Nevertheless, further studies will be needed to evaluate three-dimensional analysis of the prepared canal, and to develop a particular instrumentation sequence in order to minimize the separation rate.

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